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THE POTENTIAL USE OF POLARIZED REFLECTED LIGHT IN THE REMOTE SENSING OF SOIL MOISTURE

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THE POTENTIAL USE OF POLARIZED REFLECTED LIGHT IN THE REMOTE SENSING OF SOIL MOISTURE

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13. ABSTRACT

Polarization of light reflected from soil and sand samples is studied as surface moisture and texture of the samples are varied. A reflectometer equipped with a rotating analyzer records the polarization percentage of the reflected light. The percentage of polarization runs from 15.5% for dry soil to 89% for saturated soil, indicating that the polarization method may be viable as a remote sensing system for determining soil moistures. Background on the methods and implications of the results are presented.

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PREFACE

Figure 1 was provided by NASA, Figure 2 by the Department of Meteorology, UCLA. Figures 3-5 are adapted from graphs provided by the Department of Meteorology, UCLA.

CONTENTS

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INTRODUCTION

The ability to rapidly move mechanized equipment over all types of terrain is essential to any modern army. Since most of the earth's land surface is covered by some kind of soil, the army must concern itself with problems of soil trafficability. Some of the physical factors affecting trafficability include soil type, texture, compaction, and moisture; slope and relief; the local hydrologic situation; climate; and vegetation type and density. Of these, the most important short-term variable for a particular location is undoubtedly soil moisture. A change in moisture content of soil can make a normally trafficable zone effectively impassable to wheeled vehicles in a matter of hours.

REMOTE SOIL SENSING

A number of remote sensing techniques have been applied to the study of soils, and a few have been used to look at soil moisture. Aerial photography can be used to obtain a rough idea of the water content of a soil; one of the first Gemini photos shows a darkened swath of West Texas soil that had been dampened by a thunderstorm (Figure 1). Black and white infrared film can be used to locate water at the surface, since any water present will record as black.

The Army Engineers Waterways Experiment Station has used a four-band radar system at a 15-meter elevation to study surface water and soil moisture [1, pp. 52-53]. Other organizations have tried to apply various types of radar, including pulsed radar and radar scatterometry, to the same problem [1, pp. 53-55].

Passive microwave radiometry has shown a great deal of promise in determining surface composition and texture, moisture content, and layering. The Space General Division of Aerojet General Corp. has done extensive work in this area, including some successful tests with airborne sensors [1, p. 59]. NASA is currently interested in using polarized microwave radiation to study surface conditions [2].

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1. Needleman, S. M., and C. E. Molineux, 1969, "Earth Science Applied to Military Use of Natural Terrain," Air Force Surveys in Geophysics, No. 211.

2. Whitehead, Victor, NASA, verbal communication, 1972.

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POLARIZED REFLECTED LIGHT

Another potentially valuable remote sensing tool for the study of soil moisture would involve the phenomenon of the polarization of light when it is reflected from natural surfaces. Virtually any natural surface alters the polarization properties of light which is reflected from it. In the case of impinging sunlight, which is essentially unpolarized, the resulting reflected light will exhibit some polarization. Natural surfaces therefore fall somewhere between the two theoretical extremes of reflection properties:

(1) The Lambertian surface, from which the reflected light is unpolarized, its intensity independent of the angle of illumination; and

(2) the classical specular reflector, from which the light is completely polarized, behaving according to Fresnel's laws.

For the purpose of studying reflected earthlight, the earth's land surface has generally been considered to be a Lambertian [3, p. 4] reflector. Most surface materials, when dry, reflect light that is very weakly polarized. Undisturbed water, however, is the closest common approximation to a specular reflector, and light reflected from its surface may be nearly 100% polarized (at least in the laboratory). As water is added to a dry soil, therefore, we can expect that the percentage of polarization of light reflected from the soil will increase steadily as it more and more strongly adopts the reflecting properties of water.

Because the phenomena of reflected light are important to the study of various problems in physics and meteorology, there has been extensive work done in this area. Coulson [4] has summarized a great deal of it, including his own and that of others in the field of polarized reflected light. In 1965, Rao, Chen, Sekera, and others at UCLA, with the initial assistance of Coulson, began studying the reflection matrices of natural surfaces. They have since provided

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3. Chen, Hsi-shu, C. R. Nagaraja Rao, and Z. Sekera, 1967, "Investigations of the Polarization of Light Reflected by Natural Surfaces," Scientific Report No. 2, Contract No. 2 AF 19 (628) - 3850, Dept. of Meteorology, UCLA.

4. Coulson, C. L., 1966, "Effects of Reflection Properties of Natural Surfaces in Aerial Reconnaissance," Applied Optics, 5, 6, pp. 905-917.

theoretical backgrounds for their study and methods [3, pp. 4-12], [5], as well as extensive reports of their findings [6]. They have been interested mainly in characterizing the polarization response of light in various combinations of incidence and reflection angles, although they have also varied the surface composition to some extent.

The group at UCLA obtained noticeable differences in polarization factors when they changed the reflecting surface material. This fact suggests that the polarization of the reflected light might be studied to provide information about the surface. During the week of 28 August 1972 - 1 September 1972, the author visited Dr. Rao at his laboratory at UCLA to make preliminary measurements of the light reflected from surfaces of varying texture and moisture. The experimental apparatus and instrumentation used (see Figure 2) were similar to those described previously by Chen et al. [3, pp. 16-22], but in their present form they remain to be described more fully in a forthcoming paper.

EXPERIMENTAL PROCEDURE

In all the experiments, the illumination source angle was kept constant (53° 00' from the vertical), while the reflection angle was moved in 6° increments through most of the principal plane. Since the most significant results are in the specular half-plane (opposite the source), only these are shown for each of the tests. The reflectometer was equipped with a rotating analyzer, and the degree of plane polarization was determined by

$$P = (I_{max} - I_{min})/(I_{max} + I_{min}) \qquad (1)$$

where P is the degree of plane polarization, and I_{max} and I_{min} are the maximum and minimum values, respectively, of the radiation transmitted through the analyzer, as explained by Coulson [4, p. 910].

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5. Rao, C. R. Nagaraja, H. S. Chen, and T. Takashima, 1971, "Laboratory Determination of the Characteristic Reflection Matrices of Natural Surfaces," J. Phys. D.: Appl. Phys., 4, pp. 1057-1062.

6. Rao, C. R. Nagaraja, and Hsi-shu Chen, 1969, "An Atlas of Polarization Features of Light Reflected by Desert Sand, White Sand, and Soil," Scientific Report No. 3, Contract No. F19628-67-C-0195, Dept. of Meteorology, UCLA.

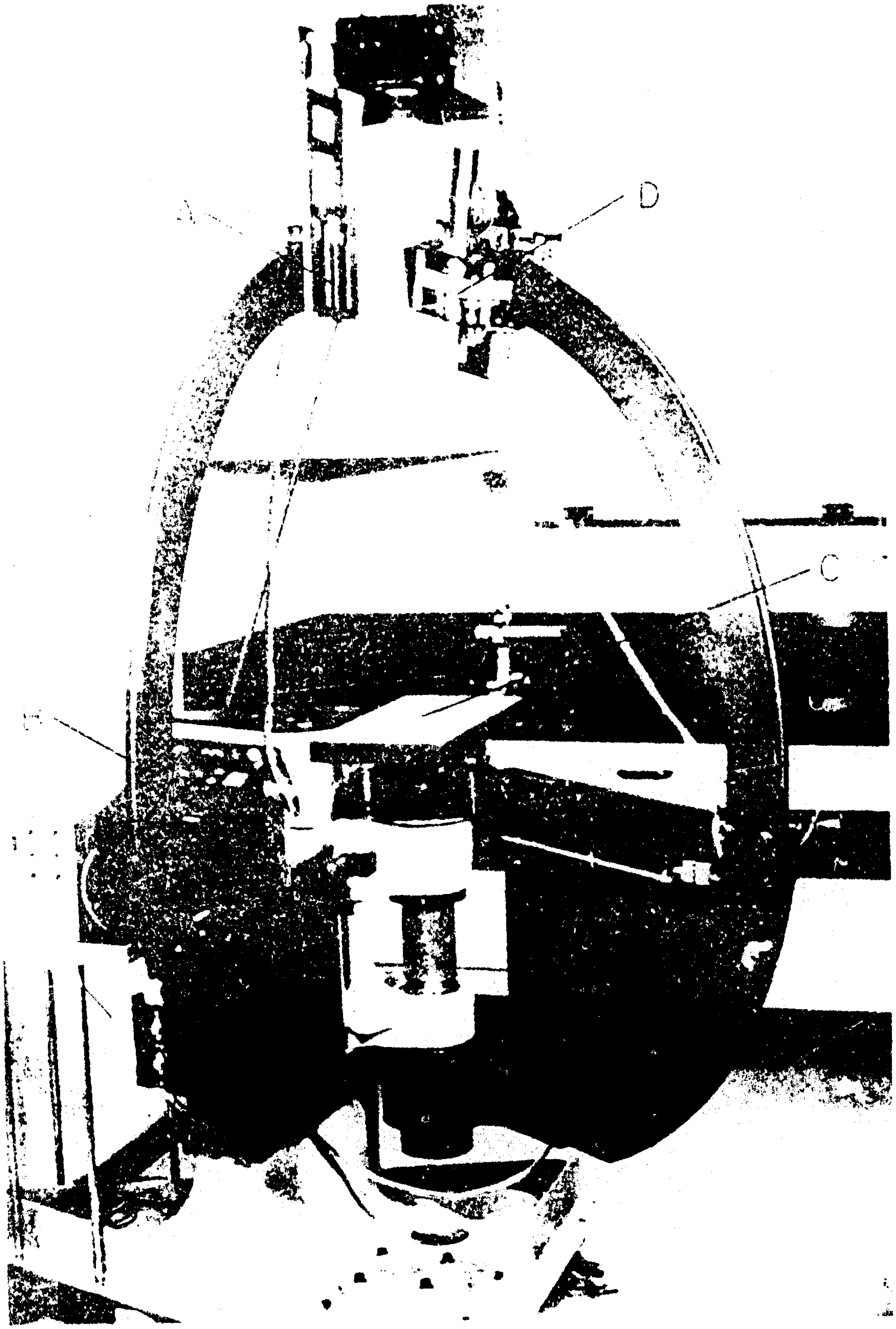


Figure 2. Experimental apparatus consisting of (A) Quartz-halogen light carriage, (B) Control panel, (C) Sample Tray, and (D) Rotating-analyzer polarimeter.

The surface material used in the texture-variation experiment was a dry, sandy, granitic soil, which was separated into four particle-size ranges. Samples were placed in trays and smoothed with a screed; results are found in Figure 3. The same soil, minus any particles larger than 0.47cm (0.185 in.), was used in the soil moisture tests (Figure 4), along with an additional sample of white gypsum sand (Figure 5). The variables introduced in the moisture tests are shown in the key following Figure 4.

Because of time limitations, we were not able to vary any properties other than texture and moisture. In the future, it would be profitable to study the effects of changing the microrelief, trace element composition, and compaction (including frozen vs unfrozen surfaces).

TEST RESULTS

The results obtained by varying the texture of the soil (Figure 3) were relatively uniform. The only significant difference in readings was between the coarsest sample, which was essentially a fine gravel, and the three finer samples. Work with still coarser samples should probably be done to fully evaluate the effect of particle size on polarization.

The tests done with sand and soil moisture (Figures 4 and 5) revealed a phenomenon which could be exploited by remote sensors. At the optimum reflection angle (approximately 60 degrees), polarization of the reflected light varied from 15.5% for dry soil to 89% for saturated soil, with a nearly linear progression of values between the extremes. The range of polarization values is such that very accurate moisture determinations should be possible, especially if previous readings have established a standard for the surface under scrutiny. In this case, as in many others connected with remote sensing, it would be quite advantageous to combine different kinds of remote sensors to maximize the obtainable information. Passes over an area of interest with IR and passive microwave sensors, for example, might provide enough compositional data to allow precise moisture determinations with a polarimeter. Any kind of meteorological data would, of course, be of great help as well (see the following section).

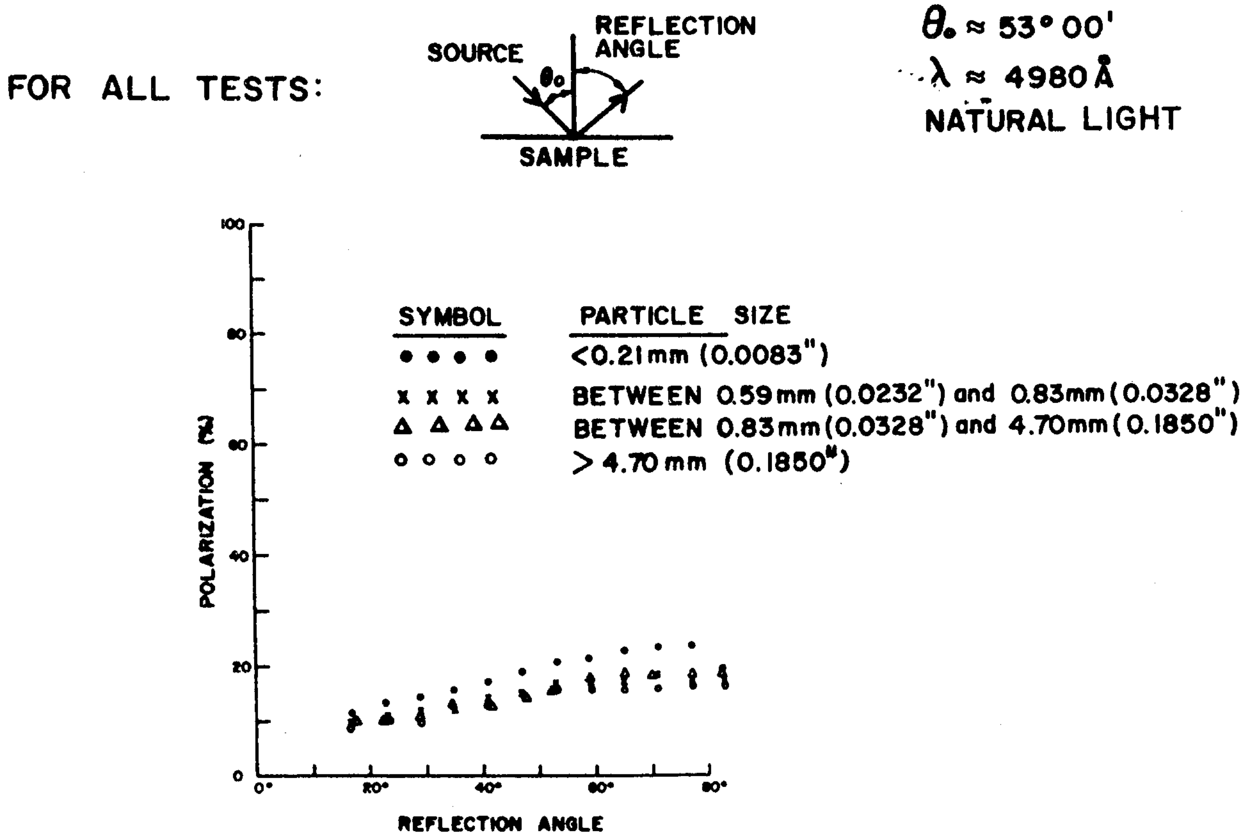
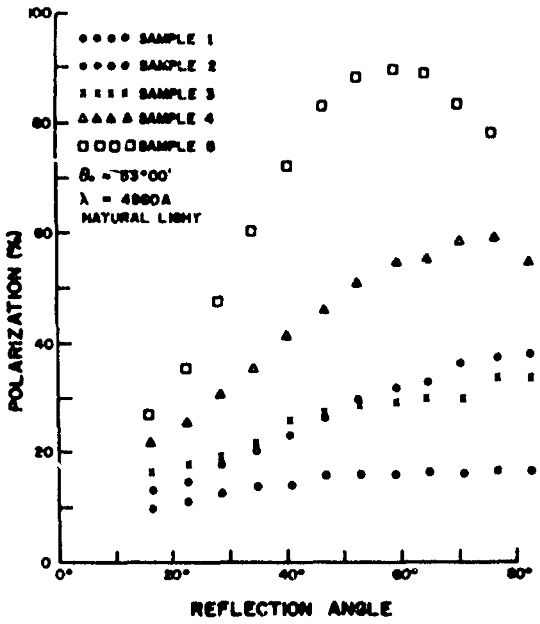


Figure 3. Dry soil, varying particle size.



LEGEND:

● ● ● ● SAMPLE 1. DRY, BROWNISH SOIL, PARTICLES SMALLER THAN 4.70mm (0.185"), SMOOTHED WITH A SCREED.

o o o o SAMPLE 2. SAME SOIL, SPRINKLED UNIFORMLY WITH WATER SURFACE DARKER THAN IN # 1. WATER CONTENT: 5.5% BY WEIGHT.

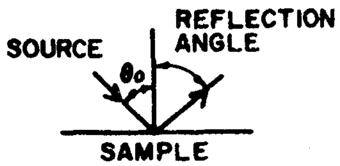
x x x x SAMPLE 3. SAME SOIL, MIXED WITH WATER BY HAND. SURFACE DARKER THAN IN # 2. USE OF A SCREED CAUSED THE SURFACE TO APPEAR TORN. WATER CONTENT: 6.8% BY WEIGHT.

△ △ △ △ SAMPLE 4. SAME AS # 3, BUT WITH WATER CONTENT OF 12.7%. SURFACE APPEARED DARKER THAN IN # 3.

□ □ □ □ SAMPLE 5. WATER WAS ADDED TO THE SOIL UNTIL IT OBTAINED THE CONSISTENCY OF SLIDING MUD. SURFACE HAD AN OVERALL GLEAM.

Figure 4. Soil, varying moisture content.

FOR ALL TESTS:



$\theta_0 \approx 53° 00'$
$\lambda \approx 4980 Å$
NATURAL LIGHT

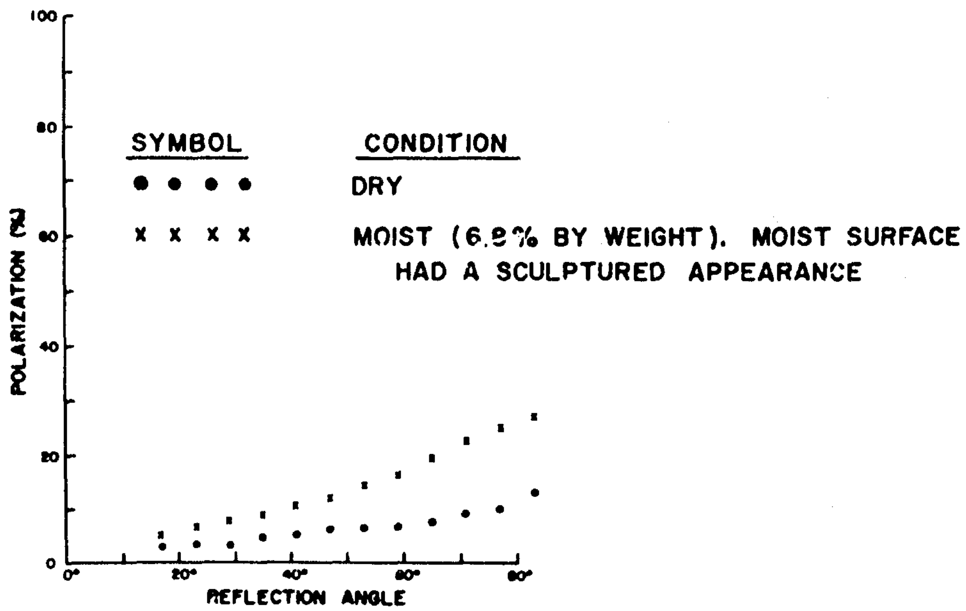


Figure 5. Gypsum sand, varying moisture content.

FURTHER CONSIDERATIONS

If a polarization analyzer is to be used as a high-altitude remote sensor, there remains the problem of transmission through a turbid atmosphere. The atmosphere itself can act as a polarizing agent, especially at the shorter visible wavelengths. Transmission of surface information would be much more effective in the yellow, red, and near-infrared bands. Research would be necessary to determine the optimum transmission bands for various applications, as well as the extent of distortions to be expected. Vertical profile meteorological instruments might be used to help correct for the distortions. Rao and others at UCLA have been studying the problem of transmission of polarized light for some time, and solutions are probably within reach.

Since the envisioned sensing system would involve optical interaction with soil particles at the surface, any physical condition which tends to limit that interaction could constitute a physical hindrance to the system. A heavy vegetative cover might conceal enough soil to make the resulting polarization percentages meaningless, depending on the optical properties of the vegetation. A heavy dew could cause misleading results in early morning readings. Each of these limiting factors would have to be field-tested from aircraft before the sensing system could be put into operation.

SUMMARY

Experiments have been performed on the extent of polarization of light reflected from natural surfaces. Although other variables remain to be tested, we have already found that a change in soil moisture has a profound effect on the polarization percentage of light reflected from the soil. This fact could be used as the basis for a remote sensing system for determining surface moistures, specifically through the use of a rotating-analyzer reflectometer as part of a satellite instrument package. Since angle of illumination and angle of observation are so important to the resulting polarization, a continual monitoring of these factors would have to be performed by computer to allow an analysis of the results. Information from other sensors would be used to help determine surface conditions.

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